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RESEARCH ARTICLE

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Isokinetic assessment of the female's soccer player's knee. A systematic review of outcomes measures

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Abstract

Background Isokinetic normative data in females' soccer players is scarce in comparison to males. Furthermore, evaluation protocols employed to obtain those data in female's studies, strongly differ from each other, using different ranges of speeds and movement patterns, thus producing different output data. Thus, it is difficult for the researcher and the clinician to choose a correct protocol for knee isokinetic test in female soccer players. Aim of this paper is to review the literature to provide updated information on how to interpret a knee isokinetic testing in healthy females.

Methods Google Scholar, PubMed, Sport Discus, and Psych info databases were queried, and 17 papers were selected. Following PRISMA methodology and PEDro scale, we classified the retrieved papers and assessed the quality.

Results In this review some common features of isokinetic testing in female soccer players of various levels of qualification are highlighted. The isokinetic performance indexes widely accepted are the hamstring/quadriceps (H/Q) ratio and dominant/non-dominant (D/ND) ratio. It also emerges that, 3 reps at the speed of 60°/sec in knee flexion/extension are preferable due to the higher reliability and that the optimal H/Q ratio in healthy female soccer players of different level of qualification and age is 50%, while the interlimb differences (D/ND) should be below 10%.

Conclusions Normative data and methodologies reviewed can be useful for the isokinetic test of female soccer players. It emerges that simplifying test procedures limiting at few testing speed and considering selected H/Q and D/ND gives all the necessary relevant informations.

Keywords Dominant non-dominant limb ratio, Errors in isokinetic dynamometry, Female soccer, Hamstring/quadriceps ratio, Isokinetic

Introduction

Female sport research has received less attention than research on male counterpart [1]. Soccer is not an exception to this rule. The reasons for this under consideration of female soccer are many, but mostly reside in social factors [1]. As consequence, research on female soccer players has been underfunded and the availability of laboratories and instrumentation to perform research in females is scarce, and usually the same evaluation protocols used in male are applied in females. Among research in female football, injuries on the knee is of special interest, albeit anatomy, hormonal aspects, neurocognitive factors have been also deeply investigated. Strength is a basic physical quality which has been largely investigated. Isokinetic testing is the most used tool for knee strength assessment in soccer and requires expensive equipment,

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which is less affordable to female clubs [1]. Despite the cost, isokinetic testing provides useful information for performance and injury prevention and rehabilitation of the knee [2].

In sport performance testing, there are basically three main factors to be considered: (a) Validity (the protocol reproduces the functional task as closely as possible and this is the case of isokinetic testing, which reproduce the ball kicking; (b) Reliability (the protocol gives similar result from day to day when no intervention is used; and (c) Sensitivity: the protocol must be able to detect small, but significant, changes in performance [3]. Sensitivity of isokinetic machine is high [3], if the system is in proper working order. As a preliminary consideration, it must be noted that knee injuries are most common in females compared to males' soccer players [4].For instance, anterior knee pain is reported more often in females than males. Isokinetic pre-season and in-season screenings are a standard part of the functional screening of soccer players, and the reference values are used as landmarks in case of injuries, to quantify the extent of strength losses and to establish the timing of the return to play after rehabilitation [5]. Quantifying the bilateral strength deficit is useful for insurance compensation procedures [6] as is useful when comparing the outcomes of different surgical methods, e.g. for the reconstruction of the anterior cruciate ligament [7].

Different types of isokinetic devices

Isokinetic measurements were first described in 1927, as a tool to measure the strength characteristic of isolated muscle fibers in the early physiological studies of muscle functions [8]. Isokinetic comes from Greek iso = same, and kinesis = motion. The first isokinetic dynamometer was developed by Levin and Wyman [8] to study the isolated giant jaw muscle fibers of the giant shark, a powerful muscle, capable of a pressure of 4000 PSI (pound per square inch). The modern isokinetic devices work by mean of a servo-controlled mechanism in a closed loop with the tested subjects, to keep the contractions speed constant with a sampling and controlling rate of 100 Hz. There are two main kinds of machines: ones who employ a circular motor (e.g. leg extension) where a leg extension arm is attached to a rotating shaft, thus measuring torque, and one who employ linear motors (e.g. leg press) and linear isokinetic devices (e.g. squat or leg press). Other type of isokinetic machines, use endless rotational motor, and are thus capable to achieving remarkably high angular velocities, up to 1000°/sec, which can be useful for some fast rotatory movements, such as downhill cycling. It is possible to spin up to 300 rpm for cadence training which is equal to 1800°/sec. Using small cranks on a stationary isokinetic bike. The availability of linear (e.g., leg press) isokinetic machines allows the measurement of the strength/speed curves in-vivo during squat-like or press-like functional exercise. The in-vivo strength/speed (or Hill's curve) is important for understanding the athlete's characteristics and adaptation to training. The basic idea of Levin and Wyman was to cancel the influence of speed of movement (causing otherwise uncontrollable acceleration and deceleration phases) on muscle contraction, thus obtaining a twofold aim: control the elastic part (pre-tensioning the muscle elastic structures) and obtaining pure strength curves [8, 9].

It is worth noting that, when considering females muscles testing, the strength characteristics of males and females' muscle are different. Males and females with the same muscle size show distinct levels of strength, given that females' quadriceps muscles by are 12% to 24% weaker compared to males, when normalized for muscle thickness [10]. Furthermore, knee injuries rate risk is higher in females than in males: one reason is the morphological condition of "genus valgus" [11], together with the joint laxity and less strength for lean body mass and muscle thickness in females [10, 12]. The prevalence of knee injuries in females is further worsened by the presence of the valgus knee, which is a common feature in the female Asian biotype [13].

Modalities of isokinetic testing and common measured parameters

Isokinetic testing can be performed in several joints using different modalities of muscle contractions. Concentric (CON) and eccentric (ECC) mode of muscle contractions are employed and a wide range of speeds, normally from 1° to 500/sec for the knee joints. The eccentric force/velocity curve in an isolated muscle, was measured for the first time using an isokinetic device [8]. The so-called eccentric contraction, or contraction-in-lengthening happens when a muscle contracts while stretched, thus resisting to the stretch in a controlled way. It has been proven that eccentric "contraction" produces higher strength levels and strength gains in comparison to purely concentric contraction. Therefore, it is worth measuring eccentric isokinetic strength to have a complete strength profile. Laterality, or dominance, is another important parameter in the physical evaluation of soccer players. It has been found that male professional soccer players of the English premiere league displayed the greatest level of inter-limb asymmetry in isokinetic strength measures (5.9–12.7%. This measure is consistent with gait asymmetry (1.6–7.7% variability in running stride length between the two legs) and jump asymmetry (0.9–7.0%) [14]. Considering psychology, isokinetic testing is strictly depended on sincerity of effort [15]. In fact, studies on sincerity of effort in healthy young females,

showed that a coefficient of variation lower than 10% in strength between 5 repetition is necessary to ascertain that the subject performed at his maximal capacities [15].

Left/Right, dominant, (D) and non-dominant (ND), knee extensors (EXT) and flexors (FLEX) strength and quadriceps/hamstrings (H/Q) ratios are widely used informative parameters for isokinetic testing [16]. It is worth noting that the Dominant leg not necessarily coincide with the Right leg, and this factor can lead to negative values when looking at the side ratios in isokinetic testing.

Effect of gravitational force and gravity compensation in isokinetic devices

H/Q ratio is of special interest because it is influenced by the effect of gravitation force during leg extension and flexion. There is also a gravity effect during the physical training, where gravitation acts against leg extensor muscle and, in turn, is favorable to knee flexors.

Gravitation force leads to an imbalance between knee extensor and flexors, stimulating the quadriceps muscle versus to hamstrings muscles. It has been proposed that this unbalanced growth of anti-gravitational muscles, can be detrimental to the safety of the knee because of muscle imbalance, thus predisposing the athlete to injuries [17]. To compensate for the measurement error due to the influence of gravitational force, isokinetic devices were equipped with a gravitational compensation procedure, which in turn can be active (the isokinetic machine arm moves the limb through the range of motion and weights -it) or passive (the limb is dropped and the isokinetic machine arm weights it during the dropping) [18]. This way, the subject limb effectively works in absence of gravitational force during testing, and the obtained H/Q ratios are cleared from the effects gravitational force.

Significance of isokinetic strength ratios

The assumption that H/Q imbalance necessarily relates to an injury, is controversial, and a recent study cast some doubt on the clinical relevance of H/Q and D/ND ratio for injury prevention [19–21]. Isokinetic force is an artificial form of muscle work, not present in nature, obtained with the help of an "artifact", the isokinetic device. Isokinetic devices present, several technical problems [22, 23] and methodological [20, 23] issues inherently linked to the isokinetic test itself. Those issues sometimes are not considered in testing and can lead to mistaken or unexplainable results. One source of error is the acceleration of the limb to "catch up" with the machine speed, which cause the torque to overshoot (similar to a sudden peak in strength), which happens when the limb "catches up" with the "true" isokinetic phase in the range of motion. The isokinetic phase of movement shortens with the increasing speed [21, 22, 24]. Therefore, the aim of this paper is to review the literature about isokinetic testing in female soccer players, to provide a survey of the available knowledge about testing protocols. The reference values for H/Q, D/ND and L/R ratios and angles of occurrence of maximal strength will be reviewed to provide a guideline for the interpretation of isokinetic testing in females soccer players.

Methods

Information sources and strategies

A survey of the existing literature was conducted in May 2023 in four different databases from inception to 10 May 2023 (PubMed, Sport Discus, Ebsco, and Psych info) and on Google Scholar. The authors performed the search using the same method independently and summarized, aggregated, organized, and compared the evidence extracted from the included studies. Given that one objective is to highlight the problems in isokinetic testing in healthy females' soccer players, the quality of the retrieved studies was one of the selection criteria of the literature. Thus, only studies published in peer reviewed journals were considered.

Screening process

Identification of the paper was made using the following keywords in different combinations on the abstracts: "isokinetic and females soccer players", "female soccer players and isokinetic", "isokinetic and knee and females and soccer", "isokinetic and soccer and females", "reliability of isokinetic systems". The word "football" was also used instead of "soccer" and in this paper we might use it interchangeability. The search strategies were combined, and duplicates were removed using Endnote X7 (Clarivate Analytics, previously Thomson Reuters, Philadelphia, PA, USA). The databases were queried in hierarchical order (e.g., first the broader database), starting from Google Scholar, followed by PubMed, Sport Discus, and Psych info. On Sport Discus only papers of higher level (level = advanced) were considered. Screening: All titles and abstracts were carefully read, and relevant articles were retrieved for review. In addition, the reference lists from both original and review articles retrieved were also reviewed.

Inclusion and exclusion criteria.

The eligibility criteria limited the search to studies performed on females' soccer players with no earlier history of injuries, e.g., pure functional or normative studies. The review was complied with the PRISMA statement for a systematic review [25]. The inclusion criteria were focused on studies related to isokinetic in healthy female soccer players of various levels of qualification, and no presence of knee pathologies. The exclusion criteria were:

(I) studies written in languages other than English, (ii) studies involving injured athletes. No limits were set concerning the year of publication. The inclusion or exclusion of articles was determined by applying the above criteria on the title and abstract as a first screening and on full texts as a second screening) but the ratios. When ratios were not reported, they were calculated from the raw values.

Data extraction

We can observe that different devices for isokinetic testing were employed in the studies, with a high heterogeneity in the raw results. Therefore considering interlimb and agonists/antagonist muscles ratios, we didn't consider the absolute strength values (torque in newton meters, Nm or power, power in Watts—in one case) but we focused on the differences in %, using the formula: (Limb with higher strength—weaker limb) / Limb with higher strength × 100 and reported as % to allow a comparison between different test conditions.

Quality assessment

Each author used the PEDro scale separately and the results were then compared. All identifiable information has been removed from the paper by a third researcher to reduce assessment bias. Any disagreements were resolved by discussion between the authors and the mean consensus score of the retrieved papers was 8/10 with high quality [26]. Limitations of the research lie in the risk that the papers could be biased by the following sources of biases: players are of different level of qualification, and/or belong to different countries with diverse cultural backgrounds which can influence training habits. The unclear definition of expert and recreational players can introduce a bias and must be considered. None of the studies reported information about training and/or fatigue status and menstrual phases. The use of different isokinetic machine is not a risk of bias, because the data are presented as ratios.

Data synthesis

Data were extracted from the papers' tables or from the papers texts and synthesized in two tables. The review has been registered in Prospero database with nr. 446,185 (CRD42023446185). The retrieved papers were also checked for the Sackett critical appraisal criteria which showed (on the mean) a Level II: Small randomized trials with uncertain results (and moderate to high risk of error) [27].

Results

We found 17 papers met the eligibility criteria and were included in the review (Fig. 1). Overall, risk of biases from different geographical location of the players, were low, being most studies performed in western world. Also, the players belong mostly or professional and collegiate

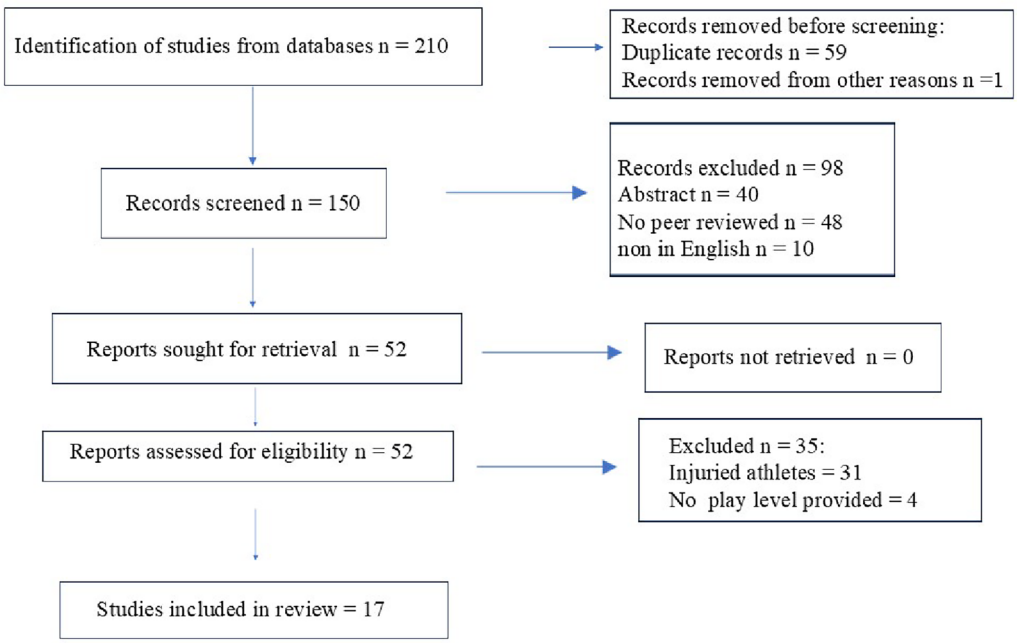

Fig. 1 Search strategy. The search strategy was performed according to PRISMA methodology. From the initial 210 papers retrieved from 5 databases, 17 papers were included in the review

Table 1 PEDro Scores of the selected studies

Study nr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
PEDro scale item eligibility	Y0es	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1 Random allocaltion	1	1	0	1	1	1	1	1	0	1	1	1	0	0	1	1	1
2 Concealed allocation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Baseline comparability	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4 Blind subjects	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5. Blind Therapist	0	1	0	0	0	0	1	1	0	1	1	1	0	0	0	1	0
6. Blind assessors	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7. Adequate follow up	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1
Intention to treat analysis	0	1	0	1	0	0	1	0	1	0	1	1	1	0	0	1	1
Between-group comparisons	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1
Point estimate variability	0	0	0	0	0	0	1	0	0	1	1	1	1	0	1	1	1
Score	4	8	5	7	5	5	9	5	5	8	9	8	7	5	7	9	8
Quality	Fair	Good	Fair	Good	Fair	Fair	Excellent	Fair	Fair	Good	Excellent	Good	Good	Fair	Good	Excellent	Good

"Fair" category (PEDro of score 4–5; n = 7), "Good" (PEDro score from 6 to 8; n = 7) "Excellent" (PEDro score of 9–10; n = 7)

level with a consistent level of training. Most studies were randomized controlled trials (RCT) (n = 10), while the rest of the studies were trials with a controlled group, but with no randomization (CT) (n = 6). PEDro [26] scores revealed a tendency towards the 'fair' category (PEDro of score 4–5) (n = 7), followed by the 'good' category (PEDro score from 6 to 8) (n = 7) and the other studies (n = 3) were classified as 'excellent' (PEDro score of 9–10). PEDro scores are reported in Table 1. Table 2 summarize the reviewed studies. Seventeen papers matched the inclusion criteria and were included in the review.

Table 1 reports the PEDro score of the papers.

Table 3 and 4 report the results for H/Q and D/ND ratio.

Comparability of different isokinetic systems

We found a few studies comparing different isokinetic systems, and must be considered that technology develops fast [32–34]. Mostly of the available literature compares two isokinetic systems [32–34] and no study on comparison of several machines exist. Of the retrieved study, Humac [35], Contrex [36] and Isomed [30] were employed in 1 study each, 8 out of 17 used a Biodex machine [38, 40, 42, 43, 47–49, 51] followed by Cybex [3 studies, 39,45,50] while Kin Com [41], Lido [46], Rev9000 [44]. This heterogeneity makes absolute normative data difficult to compare. Hamstring showed a little lower reliability in comparison to hamstrings muscles [22]. For CON EXT peak torque at 60°/sec was reported and an ICC of 0.964 was reported for on the Kin Com dynamometer [28], while on the Cybex 6000 an ICC 0.84 [28] for hamstring testing. One study compared Kin Com and Lido isokinetic machine and found no difference in muscle strength (Nm) for CON FLEX and CON EXT [29]. The Isomed system was used in one study [30], and no ICC was reported.

Modalities of contraction and velocities

Isokinetic variables were collected mostly in Concentric (CON) mode, and less often in Eccentric (ECC) mode [37, 41]. The reason for the preference of CON testing is because ECC reliability of the eccentric test is low [31], even at low testing speed (60°/sec) [32]. Also, eccentric testing can be risky for the knee safety.

The reliability of the concentric test decrease with the increase of the speed because of the shortening of the real isokinetic ROM, due to the acceleration and deceleration [35]. The chosen test speeds in the reviewed papers, ranged from 30° to 300°/sec [36–51]. Albeit there is some evidence in the literature that suggests not to use speeds above 180°/sec because of limb acceleration and deceleration time, which reduce the true isokinetic phase [22], speeds above this limit were used in 6 studies [30, 38, 39, 43, 46, 47] of 17.

Left–right limb differences

The differences between left and right limbs, which normally increase with increasing speeds, ranges from 1.7% to 9.7 at 60°/sec [38] up to 14.9% at 270°/sec in concentric leg extension [38] and from 1.9% at 60°/sec [37] up to 10.9% [41] in concentric knee flexion.

Dominant/ non-dominant limb ratio

CON and ECC Dominant (D) and Non-Dominant (ND) limb (D/ND) and Hamstring to Quadriceps (H/Q) ratio were calculated mostly using Peak Torque (PT, e.g. the maximum torque registered along the range of motion). One paper considered peak power (W) and mean work (MW) [30]. 12 of 17 studies did not report how they selected the Dominant limb (assuming as dominant the strongest in the isokinetic test), while the others selected the kicking limb as Dominant [30, 36, 40, 42]. Only 8 studies reported the D/ND ratio [30, 36–38, 40–42, 45] and three to five repetitions at slower speed (60°/sec) were measured, while at higher velocities 10 (180°sec) to 25 (300°/sec) repetitions were measured. Range of motion was in all cases 90° (from full knee extension to 90°of knee flexion).

Three studies [30, 34, 35] show a small negative D/ND ratio because of weaker dominant leg.

Normalized values for kg of body weight were used only in two studies [38, 39]. The same studies showed that young elite players have a lower difference between D/ND leg in comparison to older players. One study found a small D/ND non-significant differences between under 17 and senior elite player in CON EXT (2.04 vs 2.10 Nm/kg) and CON FLEX (2.82 vs 2.06 Nm/kg) at 60°/sec [40]. Professional players show small D/ND differences in comparison to young players on the velocity's spectrum of 60,180,240°/sec, with higher differences seen in the extensor muscles [29]. Healthy professional female players show a difference of 13% in EXT ECC at 60° and of 10% in CON EXT strength between D/DN leg [41].

H/Q ratio

H/Q ratio varies between 44.9% at 60°sec with a mean value of 56.1 ± 11.29% to 72% at 300°/sec.

Young (11–14 y.o.), elite soccer players, were found to have a H/Q ratio of 50% [42]. Olympic soccer players showed a H/Q ratio of 54% at 60°/sec and of 72% at 300°/sec [43]. Two large studies in collegiate (101 and 196 players) reported an H/Q ratio of 59.6% and of 62% at 60°/sec [44, 45]. One smaller sample study in collegiate [46] (20 subjects) showed a H/Q ratio of 44 to 50% in the range speed 60 to 360°/sec. These H/Q

Table 2 Studies included in the review and subject's characteristics

Study nr. (ref)	Author	Device	Age (years ± sd)	N	Level
1 [48]	Fillyaw 1986	Cybex	19	27	Collegiate
2 [39]	Jones 2020	Kin Com	21.2 ± 4.1	25	Prof
3 [43]	Ostenberg 1998	Cybex II	20.3 ± 4.1	101	Collegiate
4 [30]	Brigido Fernandez 2022	Isomed 2000	21.9 ± 4.19	68	Prof
5 [44]	Westing 1989	Lido	20	20	Collegiate
6 [46]	Knapik 1991	Biodex	18.9	36	Collegiate
7 [40]	Chrisman 2012	Biodex 3	11–14	92	50 elite
					42 sub-elite
8 [47]	Rosene 2001	Biodex Pro	19.3 ± 1.3	10	Collegiate
9 [45]	Vargas 2019	Biodex 4	18.21 ± 0.41	19	Prof
10 [38]	Hannon 2022	Biodex 4	11–14, 15–18	64	Recreational
11 [34]	Zhang 2021	Contrex	24.7 ± 4.2	14	Prof
12 [35]	Parpa 2020	Humac	23.6 ± 4.3	18	Prof
13 [36]	Eustace 2019	Biodex 4	21.31 ± 4.51	17	Elite
			16.91 ± 1.16 17	17	Young
14 [37]	Manson 2014	Cybex Norm	19–36	15	Prof
15 [42]	Risberg 2018	Rev 9000	29 ± 4	196	Collegiate
16 [41]	Andrade 2012	Biodex	21.3 ± 5.5	17	Olympic
17 [49]	Jenkins 2013	Biodex 4	20.3 ± 1.6	17	Collegiate

Table 3 H/Q: (hamstrings/quadriceps) ratio %

Study nr	Mode Vel°/s	CON 30	CON 60	CON 120	CON 180	CON 240	CON 270	CON 360	ECC 60	ECC 240
1			54			51				
4			52		57	62				
5			46	44	45	47		50		
6		62								
8					50					
9			44.9			72				35.4
10			50		50					
12			74							
13			49.5		57.8		58.1			
14			75						90	
15			59.6							
16			54					72		
17			86			50				

EXT: extension; FLEX: flexion; CON: concentric mode; ECC: eccentric mode. Results are reported as mean between the two legs

values are higher than those found in another study in professional players which show a ratio of 44.9% at 60°/sec [47] and in collegiate who shows H/Q values at 60°/sec equal to 49.5%, 54% and 46% [48–50], middle way between Professional and young players. One study [51] reported a functional H/Q ratio as a pooled values between concentric and eccentric force and found a 24% ratio. Also other indexes have been proposed, such as Functional hamstring-to-quadriceps ratios, which is the eccentric peak torque for the leg flexors divided by the concentric peak torque for the leg extensors [52].

Discussion

Our aims were to research the available data on functional evaluation of female soccer players of different level of qualification. Overall, the reviewed studies show a high percent of "fairs" studies when assessed with the PEDro tool (n = 7). Studies with the lowest scores are the

Table 4 Dominant/Non-dominant leg differences

Study nr	Mode Vel.°/s	EXT CON 60	EXT CON 180	EXT CON 240	EXT CON 270	EXT CON 300	FLEX CON 60	FLEX CON 180	FLEX CON 240	FLEX CON 300	EXT ECC 60	EXT ECC 180	EXT ECC 270	FLEX ECC 60
2		9.5					10.9				9.9			13.05
3		7.8	6.4											
4		5.6	3	3.6			8.2	6	6.5					
7			4.65 (E) 0,5 (R)			−1.27 (E)–1.5 (R)		2.45 (E) 2.2 (R)		5.69 (E) 5.63 (R)				
10		3.5	3.2											
11		−1.1	−0.3	−1.1			0.5	2.1	−3.4					
12		−2.1					1.9							
13		1.7	8		5.3						14.9	6.6	9.7	

EXT: extension; FLEX: flexion: CON: concentric; ECC: eccentric. E: expert players; R: recreational players. Results are reported as mean between the two legs in %

oldest one. It emerges from the review, the most used indexes in isokinetic testing are the H/Q (Hamstrings to Quadriceps) ratio [30, 36–39, 41–51] and D/ND (Dominant/Non-Dominant) difference [30, 36–38, 40–42, 45]. These two indexes, are useful to clinical practice, allow a quick evaluation and provide useful information about the status of lower limbs of females football players. Further information can be obtained from eccentric testing and high (> 120°/sec) albeit the reliability is lower. Under special conditions (e.g. special kind of isokinetic dynamometers), eccentric and high speed can be investigated for research purposes [53].

H/Q ratio

In our review, we found that there is a wide variation in the H/Q and D/ND ratio. H/Q at 60° sec is almost stable at around 50% through the literature and it is lower for young and recreational athletes. Professional athletes showed higher H/Q ratio. This result can be explained by the higher quadriceps strength of professional players. It has been shown that more training can increases the H/Q imbalance due to the antigravitational work of the quadriceps [54]. The H/Q values vary considerably among the different studies when measured at higher speeds. This is an index of lower reliability of the isokinetic test also at relatively fast speeds (120° and 180°/sec).

Dominant/non-dominant ratio

The D/ND in healthy females' soccer players is quite small and below 10%. Therefore these can be used as reference values for healthy female soccer players. We found some negative D/ND mean ratio in CON EXT and CON FLEX which is probably caused to the non-coincidence of Left and Right with ND and D leg. ECC values for knee EXT also increase with the speed, and this is explainable with the difficulty to control high eccentric speeds which are less reliable. Given that isokinetic testing is often assumed to be the "gold standard" in knee strength evaluation, the lack of information on the used protocols is quite surprising. Moreover, the warmup procedure before isokinetic tests differed widely (when described) and at times was not reported. The protocols were sometimes poorly described (e.g. no rest time between series was reported, and no previous training schedule of athletes or menstrual cycle phase at the time of test were reported). These observations agree with a recent study [50], which critically evidenced that, considering the available evidence, there need to be more investigations and an improvement in standardization of method and analysis to improve interpretation (e.g., within session and between session), adoption, and implementation of interlimb asymmetry testing, and subsequent proper interventions [50]. The same study also calls for a greater methodological rigor, to be applied in study design, data analysis, and interpretation of isokinetic testing (and other tests for asymmetry) and when reviewing the current literature.

Isokinetic testing is widely used in soccer, although only a few studies are available on females players. Therefore, a limitation of our review is the inherent lack of studies on the topic. In fact, females researches are also underrepresented in this field, and few papers are available [1]. This paucity of information about isokinetic muscular performance in females subjects, is explainable with social and economic factors (e.g., less economic interests in female soccer players value). In addition, the available literature used different isokinetic devices, different protocols of testing (speeds and number of repetitions, recovery) and the rationale for the choice of speeds are not reported. Also, is unclear how is chosen the dominant leg is chosen in several studies. There are some constants that emerges from the literature that can be summarized and can be useful for the practice and interpretation of isokinetic testing in females' soccer players. Beside reference values, we could use these results to guide the isokinetic assessment of females: (1) use slow to medium (max 120°/sec) speed; (2) eccentric evaluation is less reliable and does not added further information in comparison to concentric testing; (3) use a limited number of repetitions (3 to 5) to assess the female players; (4) use percent and normalized value to compare tests performed with different machines. Other limitations of our study were related to the fact that, we could not access the literature written in other languages than English, and we didn't consider isometric or isotonic studies to compare H/Q and D/ND in the female soccer player's knee.

A lack of information about isokinetic testing in female persist in the literature, especially in young players, despite an increase in injury rate [55].

Conclusions

We can conclude, that for clinical practice, an isokinetic test for the female's soccer athletes at 60°/sec in concentric mode for EXT and FLEX is the most reliable, employing 3 reps. H/Q should be 50% (a little bit less for young athletes), while the D/ND difference in healthy females' soccer players should be less than 10%. Several papers employed high velocities for research purposes, but previous literature [56–58] show they are less reliable due to technical issues (real isokinetic ROM, torque overshot) and do not add further information to the 60°/sec test. Therefore, it appears from our review that a 60°/sec test provide enough reliability and information on the strength characteristics of female soccer players and that testing at additional speeds does not add significant information. These results can help establish milestones

in training, rehabilitation and functional evaluation with an isokinetic machine.

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Author contributions
Cheng Zhan: conception of the study, data gathering and writing, data gathering and analysis, Antonio Cicchella, conception of the study, analysis, and writing. All authors read and approved the final version of the manuscript and approve the manuscript in full.

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